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THE PLANT BREEDER AND THE SOIL

The tendency in many modern systems of agriculture where the aim is to utilise more and more effectively the nutrient resources of the soil, is to grow better and better varieties and strains of crop-plants capable of more vigorous growth than their predecessors. Considerable success has been achieved by the plant breeder whose efforts have made this practice possible, and his services have consequently been much sought after in recent years, so that no large department of agriculture nowadays lacks a competent plant breeder on its staff.

In the tropics, best results have been obtained, using plant-breeding selection methods, with sugar-cane, maize, cotton, sorghums, rice, tobacco, ground-nut, soya bean, sweet potato, castor oil and rubber, but many other crop plants will doubtless receive attention by plant breeders in the future.

The main lines of work in plant breeding comprise breeding for quantity, breeding for quality and breeding for resistance to diseases and pests. It is with the first of these objects that we wish chiefly to concern ourselves in this article. Quantity in crop production is usually gauged by yield per acre, either of bulky vegetable material such as sugar-cane stalks, seeds such as maize-corn and oil seeds, special appendages such as cotton lint, or whole fruits such as coffee, cacao, citrus, banana, and so on. Generally speaking, the chief reason why a more vigorous variety thrives on the limited resources of a given soil better than a variety of lower vigour is that it is *capable of utilising soil nitrogen more efficiently.* Thus according to the teachings of the new science of agrobiology, in order to produce a larger number of growth units in a particular crop-plant growing in a particular soil, a new variety must be evolved which can manufacture a greater amount of carbohydrate per unit of nitrogen absorbed than can the older varieties. Thus the essential inherent biochemical difference between a variety which gives a high yield and another variety of the same crop plant which gives a lower yield when grown on the same soil in the same ecological environment so that all the growth conditions are identical, is indicated by its wider carbohydrate-nitrogen ratio, or more simply though less precisely by its lower nitrogen content per cent. dry matter.

Maximum Yield of a Crop: According to agrobiological principles, the *theoretical* maximum value for the nitrogen growth-factor is 318 lbs. per acre, which means that the greatest amount of nitrogen that can be usefully absorbed from one acre of land during one complete growth cycle by any crop-plant is 318 lbs.,* or about 160 p.p.m. of top soil 6 inches deep. Thus if all the growth factors including nitrogen are present in satisfactory amount, then the maximum yield attainable will be directly proportional to the characteristic nitrogen index for the particular variety of crop-plant that is being grown. For example, the dry matter of a certain sugar-cane variety analysed by Geerligs contained 0.084 per cent. of nitrogen. From this it follows that its maximum theoretical yield should be $318 \times 100 \div 0.084$ or 380000 lbs., or nearly 170 tons of cane per acre. Similarly the dry matter of the seed of a certain variety of maize contained 1.2 per cent. of nitrogen, and the ratio of grain to stover was 48 : 52. Hence the theoretical maximum yield of maize should be $318 \times 48 \div 1.2$ or 1272 lbs. or about 225 bushels of corn per acre. These somewhat fantastic results have indeed nearly been realised in practice. Thus yields of over 110 tons of sugar-cane per acre have been recorded in Hawaii, and yields of 200 bushels of corn per acre are often reported from the Great Corn Belt of the United States of America.

There are several ways of increasing the yields of a crop based on this agrobiological nitrogen principle. One is to improve soil conditions so that a greater proportion of the total nitrogen present may become available to the plant; another is deliberately to add extra nitrogen in the form of manure whose nitrogenous component is at least in part immediately soluble. These two are well known agricultural methods; they entail a considerable amount of supervision and expense on the part of the planter, and the degree of response of the land to treatment is variable. A further method is to grow a variety having lower characteristic nitrogen index so that the already-existing supply of available nitrogen in the soil will be more effectively utilised. This is the method made possible through the work of the plant breeder; it is simple, expedient and relatively inexpensive, so that it is usually favoured and preferred to the less certain and more costly agricultural procedures.

It does not necessarily follow that nitrogen is the only important soil factor deserving consideration in questions of yield increase; according to the law of limiting factors, other agencies may operate to prevent maximum growth, and these should be accurately identified and where possible rectified by suitable agricultural treatment if the aim is to raise the level of production. Thus the fundamental factors, water and air supply, may in some cases be inadequate or may exhibit undesirable fluctuations. Frequently, the inadequate or adverse factor may be an unsuitable soil reaction, the presence of toxic substances in the soil, or an insufficient supply of available phosphate or potash. Nevertheless it is usually the available nitrogen factor among the essential nutrients that is at fault, though the real cause may be some fundamental circumstance such as biological condition (soil micro-flora and micro-fauna), soil reaction, water-supply, or oxygen supply, that is not operating satisfactorily to produce adequate amounts of available nitrogen from the store of fixed nitrogen present in the soil. Different crop-plants doubtless respond differently to the environment by which all these essential growth factors are integrated and expressed. Thus, in the special case of plants producing bulky vegetable crop material such as the sugar-cane, although lack of available nitrogen may be the chief factor limiting growth in the majority of instances, no amount of easily assimilable nitrogen will produce maximum increase nor perhaps even raise the yields to an economic level, unless all the other contributing growth factors, particularly air and water supply and soil reaction are adequate or suitable.

The main objection to the placing of too much reliance on the plant breeder is that it tends to encourage a neglect of good husbandry. Where the planter can obtain largely-increased yields from lands of diminishing fertility by the simple procedure of replacing an old variety by a newer, more vigorous strain, without necessarily having to maintain a high standard of cultivation, he naturally tends more and more to overlook the need for soil maintenance. The down grade changes are insidious; like a bad habit they go on unsuspected until suddenly it is realised, perhaps too late, that soil exhaustion has arrived and that even the most vigorous new variety will no longer yield an increase. In similar manner the wastage of fertile land caused by soil erosion is also likely to be overlooked when satisfactory yields can still be obtained merely by taking advantage of new varieties. Indeed many cases of presumed biological failure of plant varieties by what is generally referred to as "natural deterioration" may more accurately be attributed to an unsuspected degradation of the soil, as may have been the case with some of the early soft-rinded varieties of sugar-cane. Furthermore, increasing susceptibility to certain fungous diseases, notably root-rots, may again be traced to deteriorating soil rather than to any intrinsic fault or failure of the plant variety. Even insect pests may owe epidemic spread to altering soil conditions, as in the case of the froghopper of sugar-cane in Trinidad whose oviposition appears to be determined by the mechanical suitability of a soil that has lost its granular or crumby structure.

There is thus ample reason at the present time to issue a very serious warning to planters to be on the lookout for soil deterioration and to examine carefully into their heritage of soil which may have diminished during recent years when labour

*"What is this Agrobiology?": O. W. Wilcox, Economic Forum, New York, 1936, p.302. See also Principles of Agrobiology, O. W. Wilcox, Palmer Publishing Corporation, New York 1930.

shortage, caused by war conditions, may have necessitated a curtailment of desirable agricultural practices. There has never in the past been such an urgent need as now for soil investigations and soil surveys whose primary object is to take stock of land resources and to provide the basis for improved systems of agriculture.

On the other hand, and in fairness to the plant breeder, it must be admitted that there are certain obvious limitations to the breeding of high-yielding varieties or strains of crop-plants to suit each and every kind of soil or each and every set of environmental growth conditions. Thus, whereas a variety giving relatively high yields when grown on marginal soils in poor condition will generally give much higher proportionate returns when grown on highly-fertile soils, it does not necessarily follow that it will do best on the fertile lands. It may, for instance, succumb to diseases that affect lush vegetable growths produced by rich humic soils, whereas another though lesser yielding variety may be resistant. For example, the most highly productive well-watered and well-cultivated soils in the neighbourhood of villages in the cotton lands of India cannot be used for growing cotton unless a wilt-resistant type is sown because their high humus content favours the incidence and spread of a wilt-causing strain of Fusarium fungus which is not present in poorer unirrigated lands.

The aim of the plant breeder then is to produce varieties of crop plants that will extract full benefit from the soil, while that of the good agriculturist is to ameliorate and build up his soil so that it will provide the best possible medium for plant growth. Full co-operation and understanding between the two is highly desirable and should eventually produce the best results, but the plant breeder should never allow himself to become a party to soil exploitation nor to forget the fundamental ecological principle on which all agricultural endeavour is based, namely, that the plant, the soil and the atmosphere are but the components of a single biological system, and that the plant only produces best when in complete harmony with its growth environment.

F.H.

MISCELLANEOUS NOTES

Coffee in Venezuela

A full account appears in *Agric. Venezolano* 1943, 7 : 83-4 : 20-3, 26-31, 33-7, of Arabian coffee cultivation in Venezuela, including a brief review of the somewhat primitive methods employed until recently. In Venezuela coffee must be grown under shade. The reasons for this are mentioned. Shade trees should be quick growing, of open habit, long-lived, evergreen, deep rooting and disease resistant. Such trees are to be found in the genera *Inga*, *Albizzia*, *Cassia*, and *Erythrina*. Propagation is by seed selected from the middle sections of the older primary branches of the younger trees. It is cleaned of the pulp, sterilized in hot water and sown in raised beds, with a covering of sand. Germination requires 50 days and after the formation of the first pair of leaves the seedlings are transplanted to nursery beds under artificial shade, where they remain for a year, at the end of which period they should be 50 cm. high and have 2 to 3 pairs of primary branches. The final shift to the permanent site is carried out during the rains, the planting distance recommended being 3 metres. The plants receive the customary cultivations, chiefly to control weeds. Notes are given on 8 different pruning systems. The one approved by the author for Venezuela is known as "free growth". It consists in growing on a single stem a selection of the most vigorous and best placed shoots, and eliminating the rest, and has the merits of economy of labour, of maintaining the natural habit of the plant and of causing little check. Twenty-four diseases and pests receive brief mention, some being illustrated. The wet and dry methods of extracting and curing the bean are described. The work of the National Coffee Institute, the Coffee Advisory Board, Experiment and Plant Distribution Stations, Instructional Centres for Growers and of the local Advisory Committees is touched on and provides evidence of the determination of the Venezuelans to do all that is possible to maintain and increase the reputation, already high, of their principal crop.

* * *

Effects of Hoeing

Experiments made at the John Innes Horticultural Institution on the conservation of soil moisture by hoeing appear to support Dr. Keen's (Rothamsted) views. Two plots of lettuce, and one of carrot, were laid out as 3 by 3 latin squares, the treatments being (1) unweeded, unhoed, (2) hoed weekly, (3) hand-weeded weekly. One crop of lettuce was sown *in situ* early in April and caught the worst of the summer drought. The other lettuce crop was sown in the first week of August, and the carrots in the middle of June. The results were similar in all three cases. The unweeded, unhoed plots were only half as good as the others owing to the strong growth of weeds, but there was no significant difference between hoeing and hand-weeding. The soil at Merton is light and the season was dry, therefore the tests must have been critical for the conservation of soil moisture. It seems that the only effect of hoeing was to remove the weeds, and hoeing, at present, is the most economical way of doing this.—(34th *Ann. Rept. of John Innes Horticultural Institution*).

SOME SOIL RELATIONS OF THE ROOT SYSTEM OF CACAO

Further Results of Investigations in Trinidad

BY

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(I) Introduction

In the November, 1943, issue of this journal,* the results of preliminary investigations on the root system of cacao as developed in different soil-types in Trinidad were stated and discussed. Subsequent to the publication of those results, further examination of the soils of the sites where the excavations were made have been carried out, so that a more complete picture of the distribution of cacao roots in relation to certain features of the soil may now be presented. This additional information seems to justify the scheme of classification of cacao sites that was tentatively advanced in the last article, namely :—

(I) *Shallow, nutrient-deficient clays* (exemplified by sites at Sta. Severa, Las Hermanas and El Reposo Estates; Nos. 1, 2, 3.)

(II) *Nutrient-deficient clays deepened by round-ridging* (exemplified by another site at El Reposo; No. 4).

(III) *Deep, nutrient-rich clays* (Poole and San Juan Estates; Nos. 5, 6).

(IV) *Medium-shallow, nutrient-rich loams* (San Juan; No. 7).

(V) *Deep, medium-nutrient-rich sands* (River Estate; No. 8).

(VI) *Shallow nutrient-rich sands* (Ortinola Estate; No. 8).

NOTE: This classification scheme theoretically might be expressed in complete simple form thus :—

	Clays		Sands	
	Poor	Rich	Poor	Rich
Shallow ..	(I)	—	(IV)	(VI)
Deep ..	(II)	(III)	—	(V)

The different categories so far examined in the root investigations approximately conform to this scheme, except that two main classes are not therein represented, namely, shallow, nutrient-rich clays, and deep, nutrient-deficient sands. Both these additional classes are readily recognisable among the cacao sites of Trinidad, but no root excavations have yet been made thereat. Thus shallow, nutrient-rich clays are represented by fertile heavy alluvial soils and some calcareous clays, and deep, nutrient-deficient sands by highly quartzose soil-types on which cacao has generally failed.

*The Root System of Cacao: Results of Some Preliminary Investigations in Trinidad; by C. W. R. McCreary, J. A. McDonald, V. I. Mulloon and F. Hardy, *Tropical Agriculture*, 1943, XX, 11, pp.207-220.

(II) Soil-Types Represented at the Sites Studied

The soils of Trinidad have been tentatively classified by E. M. Chenery (1939)† according to the degree of natural drainage as partly decided by the nature of their parent materials and partly by topography. The twelve more important soil-types including the seven cacao soils represented at the sites where root investigations were carried out, are tabulated below :—

(I) Drainage Free (Sands, loams, friable crumby silts and some clays; high porosity and permeability, very low water-table).

(A) *Calcareous parent materials*

(1) *Montserrat Clay-Silt* (Chocolate Soil)

Developed over glauconitic limestone forming steep hills in the western part of the Central Range.

Akin to Rendzina.

Grade I productivity;‡ good cacao soil.

Site, No. 6; San Juan (2).

It is classed in Category (III) as a deep nutrient-rich clay, but it is here not quite typical, the site being in a small valley near a stream.

(2) *Montserrat Loam* (Good Brasso Sand Soil)

Developed over glauconitic sandstone (greensand), variably calcareous, occupying steep hills in the western Central Range.

Akin to Rendzina, though somewhat podsolic.

Grade I productivity; good cacao soil, but variable.

Site, No. 7; San Juan (1).

Classed in Category (IV) as a shallow, nutrient-deficient sand, but it is here rather deep though not rich and quite non-calcareous. More typical Montserrat Loam would be placed in Category V; deep, rich sands.

(B) *Non-Calcareous parent materials*

(3) *River Fine Sand*: (Northern Range Alluvial Sandy-Loam)

Developed over quartz-mica-schist alluvium occupying river flats within the Northern Range.

Grade I to II productivity; good to marginal cacao soil.

Site, No. 8; River Estate, the Government cacao experiment station.

† *See* A Provisional Classification of the Soils of Trinidad; F. Hardy, —*Tropical Agriculture*, 1940 XVII, 8, pp. 153-158.

‡ *Grade I*:—Yield over 500 lb. dry cured cacao bean per acre.

Grade II:—Yield between 500 and 330 lb. cacao bean per acre.

Grade III:—Yield between 330 and 165 lb. cacao bean per acre.

Grade IV:—Yield below 165 lb. cacao bean per acre

Classed in Category (V) as a deep, nutrient-rich sand. At River Estate, the true water-table lies far below the surface.

Nutrient status is variable, depending partly on the degree of weathering of the component schist particles. Here, the soil is not particularly deep nor rich.

(4) *Caroni Sand*: (Bad Brasso Sand; Arena Sand; Moruga Sand)

Developed over quartzose sandstones and loose sands occupying hilly land within the Northern and Southern Plains. Variably podsolised.

Grade IV productivity; bad cacao soil; generally under forest. Not represented by any of the sites of the root investigations; *i.e.* deep, nutrient-deficient sands. The nutrient status is very low. Land mostly in forest or second-growth bush (lastro).

(5) *Maracas Sand*: (Northern Range Loams)

Developed over quartz-mica-schists, talc-schists, quartz-grits, &c. occupying hilly land in the Northern Range. Very variable, little-known soils, ranging from lateritic and podsolic to skeletal.

Grades I, II, III, productivity; good to sub-marginal cacao soil.

Site, No. 9; Ortinola.

Classed in Category (VI) as a shallow, nutrient-rich sand.

Here depth is limited by the occurrence of a gravel layer.

(II) DRAINAGE PARTIALLY IMPEDED. (Loams, marly-silts, marly-clays and sandy-clays; medium porosity and permeability through compaction and restricted perviousness of parent material, or because of depressed topography. Intermittently high water-table).

(A) *Calcareous parent materials*

(6) *Marper Silt*: (Brasso Calcareous Silt; Moruga Marly-Silt)

Developed over fine calcareous yellow sandstone or siltstone, outcropping sporadically in hilly country in south-central and north-eastern Trinidad. A Rendzina type.

Grades I to II productivity; good to marginal cacao soil.

Not represented at any of the sites; *i.e.* deep, nutrient-rich clays.

Nutrient status variable.

(7) *Princes Town Heavy Clay*: (Black Marl Soil)

Developed over porous white Globigerina marlstone, variably calcareous. A true Rendzina. Occupies an undulating belt crossing the Southern Plain.

Grade II productivity; marginal cacao soil.

Site, No. 5; Poole.

Classed in Category (III) as a deep, nutrient-rich clay, though seldom so deep nor so rich as Chocolate Soil.

(B) *Non-Calcareous parent materials*

(8) *L'Ebranche Clay-Silt*:

Developed over silty alluvium mainly occurring on the western fringe of the Nariva Swamp in East Central Trinidad, as well as in the river flats in the Central Range.

Grade I or II productivity; good to marginal cacao soil.

Not represented by any of the sites; classification would depend on depth of water-table and on the mineralogical composition of the parent material, both variable.

(9) *Sangre Grande Silty-Clay*: (Acid Clay Alluvium).

Developed over ochre-yellow alluvial silts and clays, occupying a large basin and numerous river vegas in the Northern Plain of Trinidad.

Grade II to III productivity; marginal to sub-marginal cacao soil.

Sites, Nos. 2, 3, 4; Las Hermanas and El Reposo, the first on a river vega, the second and third in the Sangre Grande basin.

Classed in Category (I) or (II), as a shallow, nutrient-deficient clay or clay deepened by round-ridging. The alluvial material is derived from weathered Northern Range schist or from sedimentary clays of the plains. The soil is generally eroded through repeated flooding, and has deteriorated in recent years.

(III) DRAINAGE IMPEDED: (Mostly stiff clays; low porosity and permeability either through compaction, restricted perviousness of top-soil, or depressed topography. No true water-table).

(A) *Calcareous parent materials*

(10) *Brasso Clay*: (Calcareous Yellow Clay):

Developed over dark-grey fine calcareous siltstone or shale, weathering to fawn or greenish-yellow stiff clay. Occupies low hilly country in the Central Range and the East (Manzanilla) District. Drainage impedence caused by imperviousness of subsoil. The profile shows Semi-Rendzina characters where its depth is appreciable.

Grades II to III productivity; marginal to sub-marginal cacao soil.

Not represented at any of the sites; *i.e.* shallow, nutrient-rich clays.

(B) *Non-Calcareous parent materials*

(11) *Ecclesville Clay*: (Bad Brasso Clay)

Developed over fine grey siltstone or shale, devoid of calcium carbonate, weathering to a dull yellow clay. Occupies hilly land within the Central Range and east part of the Southern Plain. Drainage impedence caused by subsoil imperviousness. Grades II to III productivity; marginal to sub-marginal cacao soil.

Site, No. 1; Sta. Severa.

Classed in Category (I) as a shallow, nutrient-deficient clay. Site typical of much poor hilly cacao soil.

(12) *Talparo Clay* (Red-Weathering Clay)

Similar to last, except that the parent rock weathers crimson though the humic soil is yellow-brown. Occupies hilly land in the Northern Plain and undulating country in the Southern Plain.

Grade IV productivity; poor cacao soil.

Not represented by any of the sites.

Belongs to Category (I), shallow, nutrient-deficient clays.

(III) Quantitative Assessment of Site Features

The classification scheme adopted for comparison of sites where the distribution of cacao roots was investigated and for correlating root-growth with soil features is based first on the *physiological depth* of the soil, that is, the thickness of the upper layer within which fluctuating air and water contents are favourable to root activity,* and secondly on the *richness of the soil* comprising the rooting zone, since this largely decides the general nourishment of the tree (which in turn affects root growth) and partly determines the direction of root spread and the extent of root branching which are presumably manifestations of positive chemotropism.

(1) *Method of soil sampling*: For the purpose of assessing these two major factors, the soil at the different sites was sampled in 2-foot profile pits. Arbitrary depths of sampling were employed, namely, multiples of 3 inches. Before sampling, all easily-lifted litter, root-mat and soil-crumb were carefully removed; the crumb soil was collected separately.

In six out of the total of nine cases, the actual sites where the tree excavations had originally been made were accurately located and the soil there sampled. In the remaining three cases (Nos. 1, 5 and 9), the actual sites unfortunately could not be identified, so that the soils of the fields said to have contained the sites were sampled instead.

(2) *Methods of laboratory assessment*: Both physical and chemical laboratory methods of analysis were applied to the soil samples. The soil constants that were determined comprised the following.

(A) *Physical static constants*: *Apparent* and *true specific gravity* and *index of texture*, from which total, capillary and non-capillary pore-space volumes are derived.† These values furnish a measure of the degree of aeration and the water-storing capacity of the different layers of the profile.

(B) *Chemical factors*: (i) Normal *reaction* (pH value), determined on 1 to 2.5 soil-water mixtures by means of the quinhydrone or the glass electrode; (ii) *Total organic matter* by a gasometric wet combustion (chromic acid) method:‡ (iii) *Total nitrogen* by Kjeldahl's standard method: (iv) *Carbon-nitrogen ratio*, calculated from the two last; (v) *Electrical conductivity* of 1 to 5 soil-water mixtures by Kohlrausch's modification of Wheatstone's bridge method,§ after standing at room temperature (28°C) for 21 days so as to permit nitrification and mineral hydrolysis to proceed: (vi) *Available phosphate*, by Truog's method with N/500 sulphuric acid as extracting agent, phosphate being determined in the extracts by Denige's coeruleo-molybdate method: (vii) *Available potash* (exchangeable potash) by Rice Williams' method with N/2 acetic acid as extracting agent, potash being determined by Milne's modification of the cobaltinitrite method.

The ***arbitrary limits*** provisionally accepted for nutrient factors for cacao soils in Trinidad are shown in the Table at the foot of the page.

The laboratory data are set out in Table I,‖ in which the profiles are classified according to the adopted scheme. The porosity values for each of the six serial layers of each profile are herein presented for the first time. The data are also expressed graphically in a diagram which reveals the aeration features at each of the sites.

*It is assumed on the basis of previous results that "favourable conditions of soil aeration" for cacao in Trinidad occur in soils whose free *air-space is 12 per cent. or over* of the total volume of the soil. This air-space is non-capillary, *i.e.* it consists of the larger pores whose diameters are greater than 0.01 mm. requisite for free movement of water. *See* Studies on Aeration and Water Supply in some Cacao Soils of Trinidad, by F. Hardy, *Tropical Agriculture*, 1943, XX, 5, pp. 89-104.

†For an account of the procedure, method of calculation of results and their interpretation, *see* Studies on Aeration of Cacao Soils in Trinidad, Part I; H. Vine, H. A. Thompson and F. Hardy, *Tropical Agriculture*, 1942, XIX, 9, pp. 175-180.

‡A Note on the Determination of Soil Organic Matter: A Wet Combustion Method. F. Hardy, *J. Agric. Sci.*, 1929, Vol. XIX, Part IV, pp. 727-733. Values for carbon contents were converted into organic matter contents by multiplying by an experimental-error factor, 1.33, and then by the conventional factor, 1.724.

§The Electrical Conductivity of Extracts of Soils of Different Types, and its Use in Detecting Infertility. W. R. G. Atkins, *J. Agric. Sci.*, 1924, Vol. XIV, p. 198: (Values for electrical conductivity are expressed as mhos $\times 10^{-6}$).

‖The laboratory data were abstracted from the full profile data provided by Mr. G. Rodrigues in charge of the Analytical Laboratory of the College Chemistry Department.

Nutrient Status.	Total nitrogen (Per cent.)		Avail. phosphate (Truog P_2O_5) p.p.m.		Avail. potash (Exch. K_2O) p.p.m.	
	Sands	Clays	Sands	Clays	Sands	Clays
High	.30 up	.40 up	75 up	125 up	200 up	330 up
Medium-high ..	.20–.30	.25–.40	45–75	75–125	140–200	225–330
Medium	.15–.20	.20–.25	30–45	50–75	110–140	175–225
Medium-low ..	.10–.15	.15–.20	15–30	25–50	80–110	125–175
Low	.05–.10	.10–.15	7–15	12–25	45–80	75–125
Very low	.00–.05	.00–.10	0–7	0–12	0–45	0–75

Sands:— Index of texture, 0–25; includes loams
Clays:— Index of texture, 25–60; includes silts

Table I

Physical and Chemical Laboratory Data for Main Classes of Cacao Soils

(Two-foot soil profiles)

	1	2	3	4	5	6	7	8	9	10	11
		POROSITY			NUTRIENT FEATURES						
SITE AND SOIL-TYPE	Lr. Dpth. (ins.)	Non-Capillary (Vol. per cent.)	Capillary	Index of Texture	Normal Reaction (pH)	Org. Matter (%)	Total N (%)	C/N Ratio	Electrical Conductivity (units)	Avail. P_2O_5 (p.p.m.)	Avail. K_2O (p.p.m.)
(I) SHALLOW, NUTRIENT-DEFICIENT CLAYS											
	Crumb layer			38	6.4	7.0	.38	10.5	—	30	—
(1) *Sta.Severa* (Ecclesville Clay)	3	11	44	38	5.8	2.5	.21	7.5	127	20	120
	6	2	52	38	5.5	0.9	.12	4.4	61	5	80
	9	0	53	37	5.6	0.8	.11	4.3	73	5	(85)
	12	0	51	35	5.6	0.7	.09	4.3	79	5	(80)
	18	0	50	33	5.6	0.5	.08	3.5	85	6	(80)
	24	0	48	32	5.7	0.6	.10	3.3	206	8	(90)
	Crumb layer			48	5.3	5.5	.35	9.0	140	30	135
(2) *Las Hermanas* (Sangre Grande Silty-Clay)	3	18	45	43	4.8	4.0	.30	7.6	73	22	75
	6	13	47	40	4.7	2.0	.20	5.7	54	18	69
	9	5	51	41	4.6	1.5	.15	5.4	54	14	79
	12	5	51	39	4.6	1.0	.14	4.1	52	7	70
	18	1	52	38	4.6	0.9	.13	4.0	47	7	65
	24	2	50	36	4.5	0.7	.12	3.3	56	9	50
	Crumb layer			28	5.8	6.1	.35	10.0	—	—	—
(3) *El Reposo* (1) (Sangre Grande Silty-Clay)	3	22	32	24	5.4	2.3	.15	8.7	86	44	94
	6	19	36	30	6.3	2.6	.18	8.5	(43)	23	82
	9	13	34	24	6.4	1.6	.15	6.5	67	33	(90)
	12	10	35	21	5.8	1.1	.11	5.8	21	24	(80)
	18	4	43	27	5.0	0.5	.09	3.3	44	19	(80)
	24	0	47	32	5.1	0.5	.09	3.1	37	12	(90)
(II) DEEP, NUTRIENT-DEFICIENT CLAYS—ROUND-RIDGED											
	Crumb layer			26	5.4	5.1	.26	11.2	165	17	105
(4) *El Reposo* (2) (Sangre Grande Silty-Clay)	3	28	29	26	5.0	2.9	.18	9.4	78	16	63
	6	21	32	25	5.0	2.0	.16	7.4	41	4	51
	9	16	35	26	5.0	1.6	.14	6.7	20	2	(50)
	12	14	36	26	5.1	1.5	.13	6.3	20	3	(45)
	18	12	37	26	5.0	1.1	.11	5.8	22	1	(40)
	24	9	39	26	4.9	0.6	.09	4.3	25	2	(40)

Table I.—*Continued*

Physical and Chemical Laboratory Data for Main Classes of Cacao Soils

(Two-foot soil profiles)

	1	2	3	4	5	6	7	8	9	10	11
		Porosity			Nutrient Features						
Site and Soil-type	Lr. Dpth. (ins)	Non-Capillary (vol. per cent).	Capillary	Index of Texture	Normal Reaction (pH)	Org. Matter (%)	Total N (%)	C/N Ratio	Electrical Conductivity (units)	Avail. P_2O_5 (p.p.m.)	Avail. K_2O (p.p.m.)
(III) Deep, Nutrient-Rich Clays											
	Crumb layer			72	6.9	19.3	.79	14.0	710	50	202
(5) *Poole* (Princes Town Heavy Clay)	3	21	42	63	6.7	8.2	.44	10.3	368	25	180
	6	16	46	57	6.6	3.8	.26	8.4	211	14	158
	9	14	45	53	6.6	1.6	.14	6.5	153	10	(150)
	12	13	43	51	6.8	0.8	.11	4.3	47	8	(140)
	18	9	44	51	6.7	0.4	.06	3.8	533	19	(175)
	24	13	41	48	7.2	0.3	.05	3.4	49	9	(200)
	Crumb layer			54	6.4	10.9	.57	11.1	580	310	365
(6) *San Juan* (2) (Montserrat Clay-Silt, =Chocolate Soil)	3	34	29	57	6.2	9.2	.50	10.6	330	288	230
	6	22	46	53	6.2	4.5	.37	7.0	147	168	170
	9	17	48	53	5.9	2.3	.30	4.4	56	100	(180)
	12	17	48	47	5.9	1.5	.20	4.3	42	80	(200)
	18	18	43	40	5.9	1.1	.15	4.2	48	46	(200)
	24	17	44	42	5.8	1.5	.16	5.3	44	60	(250)
(IV) Medium-Shallow, Medium-nutrient-Rich Loams or Sands											
	Crumb layer			35	6.3	7.8	.42	10.7	560	40	96
(7) *San Juan* (Montserrat Loam =Good Brasso Sand)	3	24	35	33	5.4	4.4	.29	8.9	79	32	240
	6	20	34	29	5.7	2.0	.17	6.9	66	49	200
	9	20	32	28	5.6	1.1	.11	5.8	42	14	(175)
	12	18	32	28	5.6	0.9	.08	6.1	36	13	(160)
	18	13	34	25	5.6	0.6	.07	4.8	29	16	(200)
	24	21	31	27	5.7	0.4	.06	3.9	35	39	(250)
(V) Deep, Medium-Nutrient-Rich Sands											
	Crumb layer			36	6.9	11.6	.44	15.4	570	91	76
(8) *River* (River Fine Sand)	3	23	26	18	6.8	3.3	.18	10.5	106	48	110
	6	22	24	16	6.6	1.8	.13	8.2	81	34	73
	9	22	23	16	6.3	1.7	.12	8.1	83	30	(50)
	12	20	23	16	6.3	1.5	.11	7.8	87	22	(45)
	18	20	25	17	6.2	1.2	.10	6.9	71	21	(55)
	24	20	22	14	5.6	0.8	.08	5.7	75	17	(65)
(VI) Shallow Nutrient-Rich Sands											
	Crumb layer			—	—	—	—	—	—	—	—
(9) *Ortinola* (Maracas Sand)	3	36	18	18	7.0	5.7	.30	10.9	186	133	106
	6	38	15	14	6.3	2.9	.15	11.0	65	149	112
	9	38	14	12	6.1	1.5	.10	8.6	48	135	100
	12	38	12	11	5.7	1.0	.09	8.2	36	122	97
	18	35	12	14	5.1	0.7	.07	5.7	38	108	87
	24	33	14	6	5.0	0.4	.07	3.3	56	122	82

(IV) Discussion of the Laboratory Data

(1) POROSITY AND SOIL STRUCTURE

The information concerning porosity contained in Table I and the diagram demonstrates that the soils at the different sites vary widely in physical features, as follows.

(A) *The shallow clays* (top row of diagram) show adequate aeration only down to relatively small depth. Evidently values for non-capillary pore-space greater than 12 per cent. of the total volume (the critical value) are here exhibited only by a superficial layer up to 12 inches thick but seldom more than 6 inches.

The shallow clays generally possess a distinct *crumb layer* immediately below the covering of rotting leaf litter. Its thickness is usually only about $\frac{1}{2}$ inch though occasionally greater. The crumb soil is highly porous, spongy and soft; it does not generally merge into the soil below, but is typically sharply separated from it. There is no doubt however that this crumb layer is an intrinsic part of the complete profile (as in normal forest soils), and that its absence denotes profile truncation brought about by erosion, for example, through repeated flooding and unrestricted rapid runoff or through hillwash. Its presence greatly increases the aeration of the surface soil abundantly occupied by fibrous roots.

During rainy weather, the air-space volume of the upper soil layers is considerably reduced because of drainage impedence due to imperviousness of the layers below, or by flatness of topography which favours a high water-table. It has previously been demonstrated by means of periodic measurements of water and air contents* that shallow clays (for example, Sangre Grande Silty-Clay) possess 12 per cent. or more of free air-space volume (the critical value) in the surface 6-inch layer only for half the year, and in the second 6-inch layer only for one-fifth of the year. They are thus very inadequately aerated except toward the end of the dry season when water shortage becomes acute so that drought may then operate as the limiting factor for root activity. Such water-logged shallow clays evidently present extreme adverse physical conditions; *their suitability for cacao-growing would appear largely to depend on the presence of a superficial crumb layer which is an ideal medium for root activity.*

(B) The *deep clays* (second row of diagram), generally exhibit values for non-capillary pore-space greater than 12 per cent. down to the full depth of the 2-foot profile and possibly much deeper in certain cases. These soils owe their subsoil porosity to different causes. The first (No. 4) is an artificially made-up soil which has been round-ridged to a depth of about 20 inches, otherwise it would be like No. 3 (an undisturbed profile) in which adequate aeration is restricted to the shallow surface layer. Evidently the slightly increased porosity imparted to this soil by operations deliberately repeated at intervals over a long period of time has been retained intact, though doubtless non-capillary porosity is slowly diminishing with the years.

The second and third examples (Nos. 5 and 6) each owes its deep subsoil porosity to the open structure of the parent rock which is a marlstone resembling hard chalk in the one case and a soft granular sandstone in the other. The decomposing rock appears at 20 inches depth in the first example but at a greater indefinite depth in the second. Both parent rocks yield heavy clays when weathered, and the high calcium status of these clays, together with the presence of much ferruginous matter, doubtless account for their small-clod structure which enhances subsoil porosity.

The surface soil, as in the shallow clays, exhibits a conspicuous *crumb layer* which is exceptionally thick and remarkably stable in the Chocolate Soil (No. 6). The humic soil just below the crumb is also well-structured, friable and crumbly.

(C) The *shallow sands* (third row of diagram) occur chiefly over alluvial flats where a high water-table limits their physiological depth. Occasionally extreme compactness induced by small particle size (as in example No. 7), or by incipient cementation, or by a clayey infill, impede downward drainage, or the occurrence of a gravel layer near the surface (as in example No. 9) prevents upward water movement during drought, thus limiting the depth of the rooting zone. In other cases, excessivley large non-capillary pore-space (values over 25 per cent.) causes wide fluctuation in water-supply, so that cacao trees growing in the coarser representatives are subject to harmful water-strain.

Fine-grained shallow sands usually possess a well-marked superficial *crumb layer*, not so conspicuous in the coarser kinds. The sand grains are held together mainly by fibrous roots rather than humus cement. Such crumb generally lacks stability and rapidly disintegrates when the protecting litter is lost.

(D) The *deep sands* (third row of diagram) occur either over dry river terraces or high-level alluvial flats, or they occupy steep hill-slopes. Like the last, they may be subject to harmful fluctuations in water and air contents when their non-capillary pore-space is large. They include medium-coarse sands having single-grain structure, over which the superficial *crumb layer* is usually only sparsely developed. Example No. 8, River Estate, is perhaps too fine-grained to be typical of the better-drained phases of deep sands.

(2) ORGANIC MATTER CONTENT AND STRUCTURAL POROSITY

The nine profiles vary markedly in organic status and in depth of humic penetration. The most highly organic soils are the two Rendzina soils (Nos. 5 and 6; see diagram) which also show the deepest humic penetration. The least organic are the nutrient-deficient clays (Nos. 1 to 4) in which humic penetration is very shallow (4 to 9 ins.), excepting the round-ridged soil (No. 4) in

*Studies in Aeration and Water Supply in Some Cacao Soils of Trinidad, F. Hardy.—*Tropical Agriculture*, 1943, XX, 5, pp. 89-104.

which it is deeper (12 ins.). There appears to be a close connection between organic status and structural porosity; this relationship has already been stressed in the previous article and the data now presented provide confirmatory evidence in its support. The paramount importance of organic matter in conferring a stable porous structure on soils, particularly clays, has been repeatedly stressed in recent agricultural writings; the subject requires no further elaboration in this place.

Undoubtedly *organic matter is the chief agent that has imparted an effective non-capillary porosity to the upper layers of the clay soils* concerned in these investigations. In the case of the sandy soils, porosity of course is partly or mainly decided by the size of the component grains, and here organic matter is not so important as a structure-former.

Loss of the organic upper layers through erosion or wastage must obviously be attended by serious reduction in physiological depth in clay soils, and by a gradual falling off in their suitability for root development. During soil erosion, the layer first to be affected is the *crumb layer* whose content of organic matter is very high. Thus in the soils examined, the organic content of the crumb on the average is more than twice that of the 3-inch layer immediately below it (Table I : Column 6); the increase in passing from the crumb layer to the next below it ranges from about 40 to 250 per cent.

(3) Organic Matter Content and Nutrient Status

Quite apart from the important physical attributes which organic matter confers on soils, this component also largely decides their richness. Not only does it comprise the sole source of *nitrogen*, but it also provides abundant *phosphorus*, mainly in organic combination yet easily transformed into available phosphate by further biological breakdown and oxidation. The humus fraction of the organic matter also contains *potassium* firmly held by adsorption against loss by leaching but yet readily available to plants.

Comparison of the numerical data for total nitrogen, available phosphate and available potash with the data for organic matter contents of the different layers of the soils examined, including the crumb layer (Table I), reveals close quantitative relationships. Thus the most highly organic Rendzina soils (Nos. 5 and 6) exhibit the highest contents of total nitrogen and available potash, and one of them (No. 6) shows the highest available phosphate content. Furthermore, they also show the highest electrical conductivity values, a fact which cannot be attributed to the presence of free calcium carbonate, since each soil is distinctly acid. On the other hand, the four shallow clays (Nos. 1 to 4) have the lowest contents of organic matter commensurate with their low contents of nitrogen and available phosphate and potash and with their low electrical conductivity values.

It is thus evident that, in cacao soils such as these, organic matter is the main source of plant nutrients and that its concentration in the upper soil layers not only markedly affects their physical properties but also decides their richness. Consequently, the depth of the nutrient zone generally coincides with the depth of humic penetration, so that a determination of the organic status is often sufficient to assess in many cases, not only a soil's physical condition, but also its nutrient status and hence its suitability for root development.

Circulation of nutrients: The generally-accepted explanation of the high concentration of nutrients within the organic part of the soil profile is that a circulation of nutrients is initiated when a site is occupied by a natural plant association. For example the more deeply-rooted members of a forest association gradually remove soluble mineral matter from the zone of decomposing parent rock (except that which is lost by leaching) and fix it for a time in their stem systems above-ground. Eventually, through the shedding of leaves, flowers, fruits and twigs, and finally by the death and breakup of the trees themselves, all this mineral matter is returned to the soil surface where it still remains in close association with the organic residues undergoing decomposition and humification through the activity of micro-organisms which assimilate much of it into their own cells. Some of the products of decomposition are carried downwards by percolating water or by the agency of soil animals so that an organic profile gradually appears. As more and more of the soluble mineral matter is removed from the zone of decomposing parent rock, a middle layer of base-depleted inert mineral residues appears. This may be called the "*dead layer*". One of its chief features is that it becomes increasingly acid as the bases are removed from it and as root activity proceeds.*

It is evident from these facts that the rate at which a "dead layer" develops above the parent rock and below the nutrient-rich humic layer will depend primarily on the *mineralogical composition of the parent rock*. If the parent rock contains abundant mutable minerals (for example, crystalline igneous rocks such as granite or andesite) then the development of a dead layer may require a very long period of time, whereas if the parent rock already consists of inert mineral residues (for example, old alluvial deposits and sedimentary rocks such as kaolinic claystones) then the formation of a dead layer may be relatively rapid.

(4) Nutrient Status and Parent Rock

Table II presents average values (weighted means) for the laboratory data for the whole profiles, exclusive of crumb layers, and Table III brings together the laboratory data for the crumb layers alone. The deepest layer sampled (18 to 24 ins.) was not deep enough to portray the character of the material within the zone of decomposing parent rock, so that the presence or

C. W. R. McCreary, J. A. McDonald, V. I. Mulloon and F. Hardy. The Root System of Cacao; *Tropical Agriculture*, 1943, XX, 11, pp.207-220. *See* p.215.

*See Some Aspects of Cacao Soil Fertility in Trinidad; F. Hardy—*Tropical Agriculture*, 1936, XIII, 12, pp. 315-317.

Table II: Mean Values for Nutrient Factors: (1) Whole Profiles

Crumb layer disregarded

(Averaged laboratory data for 2-foot profiles)

Site	Soil-Type	4 I.T.	5 pH	6 O.M. (%)	7 Total N (%)	8 C/N Ratio	9 Electrical Conductivity (units)	10 Avail. P_2O_5 (p.p.m.)	11 Avail. K_2O (p.p.m.)	12 Total Marks (Max 100) †
(A) Nutrient-Deficient Soils										
(1) Sta. Severa ..	Ecclesville Clay ..	35	5.6	0.9	.11	4.7	84	8	88	32
(2) Las Hermanas	S.G.Silty-Clay ..	39	4.6	1.5	.16	5.3	55	12	65	36
(3) El Reposo (1)	do. ..	27	5.5	1.2	.12	7.1	47	23	86	29
(4) El Reposo (2)	do. ..	26	5.0	1.4	.12	6.7	32	4	46	14
(B) Nutrient-Rich Soils										
(5) Poole ..	P. T. Heavy Clay ..	53	6.8	2.0	.15	7.7	143	14	172	89
(6) San Juan (2)	"Chocolate Soil"	47	6.0	2.8	.25	10.7	95	106	211	100
(7) San Juan (1)	Montserrat Loam	28	5.6	1.3	.12	6.2	44	26	212	61
(8) River ..	River Fine Sand ..	16	6.2	1.5	.11	7.8	81	26	65	60
(9) Ortinola ..	Maracas Sand ..	12	5.7	1.7	.12	8.1	65	125	94	73

Table III: Mean Values for Nutrient Factors: (2) Crumb Layers

Site	Soil-Type	4 I.T.	5 p.H	6 O.M. (%)	7 Total N (%)	8 C/N Ratio	9 Electrical Conductivity (units)	10 Avail. P_2O_5 (p.p.m.)	11 Avail. K_2O (p.p.m.)	12 Total Marks (Max. 100) †
(A) Nutrient-Deficient Soils										
(1) Sta. Severa ..	Ecclesville Clay ..	38	6.4	7.0	.38	10.5	—	30	—	33
(2) Las Hermanas	S.G. Silty-Clay ..	48	5.3	5.5	.35	9.0	140	36	135	31
(3) El Reposo (1)	do. ..	28	5.8	6.1	.35	10.0	—	—	—	18
(4) El Reposo (2)	do. ..	26	5.4	5.1	.26	11.2	165	17	105	21
(B) Nutrient-Rich Soils										
(5) Poole ..	P.T. Heavy Clay ..	72	6.9	19.3	.79	14.0	710	50	202	100
(6) San Juan ..	"Chocolate Soil"	54	6.4	10.9	.57	11.1	580	310	365	92
(7) San Juan (1)	Montserrat Loam ..	35	6.3	7.8	.42	10.7	560	40	96	59
(8) River ..	River Fine Sand ..	36	6.9	11.6	.44	15.4	570	91	76	92
(9) Ortinola ..	Maracas Sand* ..	—	—	—	—	—	—	—	—	—

* No sample collected.

† The values in this column were derived by means of a scale of marks applied to the chemical data in columns 5, 7, 9, 10 and 11.

absence of a depleted "dead layer" occurring below the humic nutrient-rich top-soil is not revealed. Nevertheless the mean values for the whole profiles show that the soils differ in richness, and that the nutrient status of each is closely related to its organic status. Similarly, the nutrient values for the crumb layer vary; they sharply differentiate the nutrient-deficient soils (Nos. 1 to 4) from the rich soils (Nos. 5 to 8).

The best soil is clearly No. 6 ("Chocolate" Soil), which is very rich in nutrients as well as in organic matter. It is closely followed by No. 5 (the other Rendzina soil) and then by Nos. 9, 7 and 8, these five comprising all the nutrient-rich soils of the series, and incidentally the most productive of cacao.

It is significant that each of the "good" soils is derived from a parent rock containing a characteristically high content of mutable minerals.

The soil at Site No. 6 is derived from a ferruginous sandy limestone rich in potash-bearing glauconite and in phosphatic calcareous fossils; it also contains appreciable manganese. That at Site No. 5 is derived from a marlstone rich in some potash-bearing mineral, possibly hydrous mica, though it is peculiarly deficient in phosphate. That at Site No. 9 is derived from alluvial, colluvial or detrital material comprising variable schists containing some potash mineral, as well as abundant phosphate. That at Site No. 7 is derived from a highly glauconitic greensand, and that at Site No. 8 from schist alluvium resembling the parent rock of No. 9.

The worst soils contain least amounts of organic matter and are very deficient in phosphate and potash. They are derived from parent materials that represent end-products of profound weathering.

The soils at Sites Nos. 2, 3, 4 are derived from old alluvial deposits occupying river basins and levees of the Northern Plain which have been much altered and leached since they were originally removed from their source among the variable schists of the Northern Range. Their parent materials are probably ferruginous kaolin with only small amounts of potash minerals and phosphatic residues.

The soil at Site No. 1 is derived from a reworked sedimentary clay similar in composition to No. 4.

Evidently the mineralogical composition of the parent rock from which each of these soils has been derived has largely decided the richness of the upper humic layer that has ultimately developed from it through the agency of plants (comprising both micro-organisms and forest vegetation) and soil animals. It has also apparently played a part in deciding the relative amount of organic matter produced, assuming other factors to have operated equally and no erosion to have occurred.

Where a *crumb layer* has developed, a marked concentration of nitrogenous organic matter and mineral nutrients has proceeded (Table III), thus conferring especial significance on this layer as a very suitable medium for root growth. Its richness, indeed, seems to reflect and to emphasise the general nutrient status of the whole soil. Where the parent rock, the mineral profile and the organic component of the soil possess high nutrient status, the crumb layer is especially rich, but where the rock and its derived soil possess only low nutrient status, then the crumb layer also tends to be deficient in nutrients and not to differ much in chemical composition from the humic soil lying immediately below it. These striking features are clearly shown by a comparison of the laboratory data contained in Tables I and III.

(5) Reaction in Relation to Nutrient Status

Reference again to the tabulated laboratory data for the different profiles reveals the further fact that the four nutrient-deficient clays (Nos. 1 to 4) and the medium-rich loam (No. 7) are markedly acid throughout the profile (pH 5.8 or less), whereas the nutrient-rich clays and sands (Nos. 5, 6, 8, 9) are only slightly acid to neutral (pH 6.0 to 7.0) at least within their main rooting zones. Some relationship thus exists between nutrient status and reaction, which is to be expected on the grounds that the more readily-available nutrient bases (potassium, calcium, magnesium) occur in fertile soils mainly as exchangeable ions which are replaced by hydrogen-ions in the less-fertile soils that have lost most of their store of nutrients through mineral hydrolysis and leaching.

The reaction data show a tendency in all cases for the upper humic layers to exhibit lesser degrees of acidity (*i.e.* higher reaction values) than the layers below.* This tendency is particularly well shown by the crumb layer which is invariably the least acid layer of all. In the case of the nutrient-deficient soils, the reaction value for the crumb layer deviates more from that of the soil below than in the case of the nutrient-rich soils whose crumb layers do not differ much in reaction nor (as has already been noted) in nutrient status from the layers immediately beneath them.

These characteristics of the reaction profile are doubtless further manifestations of the circulation of nutrients which is set up through the agency of actively-growing vegetation. Had the profile pits been dug deeper, the higher pH values of the parent soil materials as compared with those of the incipient "dead layers" would also have been revealed; the tendency is just discernible in some cases, notably No. 5, the Rendzina derived from marlstone.

The fact that the least satisfactory cacao soils display highly acid "dead layers" because of a dearth of bases, suggests that soil acidity *per se* is not a primary factor controlling root distribution, though it may serve as an *index* of unsuitable conditions for root growth. The real causative factor appears to be a low nutrient base status.†

*The pH scale is logarithmic, so that a decrease of one unit implies a tenfold increase in acidity and of 0.5 unit, a three-fold increase.

†An even simpler index of unsuitable conditions for root growth in-so-far as the nutrient factor is responsible may be the depth of the red colouration given by the soil to Comber's reagent, which may be taken as a rough measure of base depletion. The results of Comber tests applied to the soil samples collected in this investigation (but not here recorded) support this contention.

(V) Relationships between Soil Factors and Root Distribution

Introduction: One of the main objects of our ecological soil investigations has been to define a "good" cacao soil and to determine in what respects it differs from a "bad". The methods of ecological research in the sense here implied are strictly quantitative. As many growth factors as possible are periodically measured and their comparative fluctuations within different cacao environments of known producing capacity are systematically traced over several growing seasons. The procedure as applied to two contrasted "good" and "bad" cacao plots in Trinidad has already been fully described and the results have been discussed in detail.* Certain of the conclusions reached have been put to test by means of manurial experiments carried out in fields comprising different soil-types.* Finally, the relative importance of all the factors found to contribute to high production of cacao in Trinidad were appraised† and, by a process of elimination, the important conclusion was reached that in *most cases where yields are low or have declined in recent years it is the root relations of the cacao tree that seem to be mainly at fault.* This conclusion naturally led to the initiation of detailed studies of aeration and water-supply in cacao soils and to a general investigation of the rooting habits of the cacao tree in soils of different kinds which have been described in our more recent publications.

Soil development: Fertile soils are produced from different parent rocks by the operation of two main agencies, climate and organisms, including green plants, micro-organisms and soil animals. Provided the topography is suitable and that sufficient time is allowed, a characteristic kind of soil evolves within each climatic zone of the earth's surface. Wherever the rate of soil genesis exceeds that of soil erosion, a distinctive profile eventually develops whose main features are decided by the relative efficacy and interplay of these five major soil-forming factors. The organic part of this profile exercises a predominant rôle in deciding the properties and behaviour of the soil when it is utilised for crop growing.

The organic profile: A natural forest soil or a cacao soil adapted from it, as developed for example in Trinidad, exhibits a typical distribution of organic matter. First there is a distinct layer of fresh litter consisting of recently-fallen leaves, flowers, fruits and twigs, in which the component parts are easily recognisable. Below this the litter is largely decayed though the original structures may still be discernible. Within a short distance, only blackened leaf fragments and rotten woody material occur as remnants of plant decay, and these are interwoven with conspicuous white mycelia of various fungi and with insect frass and the dead bodies of soil animals and microscopic organisms.

Closely associated with the rotting litter and apparently attached thereto by means of fungal hyphae is a mass of fibrous tree roots, often sufficiently abundant as to form a distinct mat (*biché* or *bichet*). Many of these rootlets when actively growing are white and swollen at the ends, resembling small quills, and sub-terminal root-hairs or mycorrhizae grow out plentifully from them.

Next below the litter is a well-marked layer of *soil crumb* in which mineral matter and organic residues are closely associated, the organic matter acting partly as a cement binding the mineral grains together to form highly porous stable aggregates whose size ranges from about 5.0 to 0.5 mm. Within the crumb layer fibrous roots ramify abundantly, joining up with the overlying root-mat. Below, the crumb layer usually merges imperceptibly into humic friable soil comprising the upper part of the profile proper, but in certain cases it forms a separate and distinct covering, especially in the heavier and more compact soils. The unique physical features and the high nutrient status of this crumb layer have already been stressed, and the fact that it plays a particularly important rôle in conferring fertility on the less nutrient-rich clay soils has been emphasised.

The rest of the rooting zone of forest and cacao soils as represented in Trinidad consists of weathered mineral residues associated with diminishing amounts of organic matter carried mechanically or having percolated in solution downwards from the decomposing layer of surface litter. The nutrient status and the physical properties of this humic soil, as we have seen, are equally important in controlling the distribution of roots of cacao trees as well as forest trees.

The depth of penetration and the biochemical composition of this soil organic matter differ markedly in soils of different texture and structure, deepest penetration and least biochemical breakdown occurring in sandy and open-structured soils as contrasted with compact silts and clays.

Cacao root system: The cacao tree possesses a well-marked *tap-root* whose dimensions and form are apparently mainly decided by the penetrability of the subsoil, as was found to be the case in the preliminary investigations carried out in Trinidad described in the previous article.* The best-formed tap-roots occur in the poorest and the most compact clayey soils (for example, Ecclesville Clay and Sangre Grande Silty-Clay) having marked "dead layers" through which tap-roots must penetrate in order to reach a supply of assimilable nutrients and easily-available water in the zone of rock decomposition. On the other hand, the

*Annual Reports on Cacao Research; I.C.T.A., 1932 onwards. A comprehensive summary of the more important conclusions reached after five years of ecological investigations is given at pp. 25-28 of the Fifth Annual Report for 1935, issued in 1936.

†The Maximum Yield of Cacao; F. Hardy, *Tropical Agriculture*, 1939, XVI, 8, pp. 179-191.

*The Root System of Cacao; C. W. R. McCreary, J. A. McDonald, V. I. Mulloon and F. Hardy, *Tropical Agriculture*, 1943, XX, 11, pp. 207-220.

shortest and worst-formed tap-roots occur in the best soils (for example, Chocolate Soil), presenting adequate water and nutrient supplies throughout the profile.

Lateral woody roots are inserted in whorls in the upper part of the tap-root. The number of distinct whorls, the number of laterals in each whorl, the thickness and length of the laterals and the extent of branching appear to be decided mainly by the features of the soil. In compact clay soils having only shallow humic penetration, the laterals are relatively few in number; they are thin but long, sparsely-branched and often tortuous, whereas in open-structured soils having deep humic penetration they tend to be numerous though thick, short and straight and much branched. The stoutest and longest laterals are usually inserted nearest the soil surface where the organic content is highest.

Fibrous rootlets are entirely restricted to humic soil; their density seems to depend on the quantity of organic matter present which mainly decides porosity and therefore the degree of aeration. They are especially abundant within well-rotted litter and crumb soil which normally comprise the upper part of the soil profile. In compact clay soils they are almost entirely confined thereto, but in open-structured soils they may ramify within a much thicker zone of humic mineral soil, so that a fibrous root mat (*biché* or *bichet*) is here more-or-less absent.

Thus, physiologically-deep nutrient-rich soils typically display a wide root distribution, every part of the humic soil being explored by branching roots ending in tufts of fibrous rootlets. In this respect these soils differ from physiologically-shallow nutrient-deficient soils in which root distribution is confined to a thin surface layer, the fibrous rootlets comprising a well-marked root-mat covering the surface like a blanket.

The possibility that fibrous rootlets possess a special function in producing a *growth-promoting hormone* has already been indicated in the previous article in which reference was made to a recent discovery announced by Dr. F. W. Went of the California Institute of Technology. This growth hormone apparently is only formed in rootlets that are surrounded by moist air, thus necessitating plentiful soil aeration for their development. The special importance of the presence of a surface crumb layer is further indicated by the discovery, and the harmful effects likely to follow on its loss through erosion, accompanied by the compaction and encrustation of the mineral soil thus exposed, should not be over-looked when considering the relationships that exist between soil factors and cacao root distribution.

(VI) Summary

(1) This article presents further quantitative evidence of the close relationship that exists between certain physical and chemical features of the soil and the distribution of roots of the cacao tree in Trinidad.

(2) Full laboratory and field data for nine typical cacao sites are tabulated and discussed. The sites represent a texture range of soils presenting differing degrees of drainage-impedence, permeability, air and water supply, nutrient supply and acidity.

(3) For purposes of correlating root distribution with soil features, the sites are classified according to "physiological depth" and nutrient status or "richness". *Physiological depth* is decided by the degree of aeration of the successive soil layers of the profile; it may be limited by a high water-table induced by flat or depressed topography, otherwise it is determined by soil structure. *Nutrient status* controls the chemotropic response of the root system and the general nourishment of the plant as a whole.

(4) The data indicate that non-capillary pore-space (which provides the main air storage) in the clay soils examined depends mainly on organic matter content, being greatest in the crumb layer and diminishing with depth in the soil below.

(5) The data further indicate that nutrient status also depends on organic matter content, though the chemical composition of soil organic matter is primarily decided by the mineralogical composition of the parent rock, since a circulation of nutrients transfers soluble substances from the decomposing rock to the soil surface *via* the growing plant.

(6) Soil acidity (which varies markedly at the different sites and in the different layers of each profile) is regarded as an index of nutrient deficiency. The less-productive nutrient-deficient soils exhibit a relatively highly acid "*dead layer*" lying immediately below the humic topsoil. Root distribution is sparse within this layer.

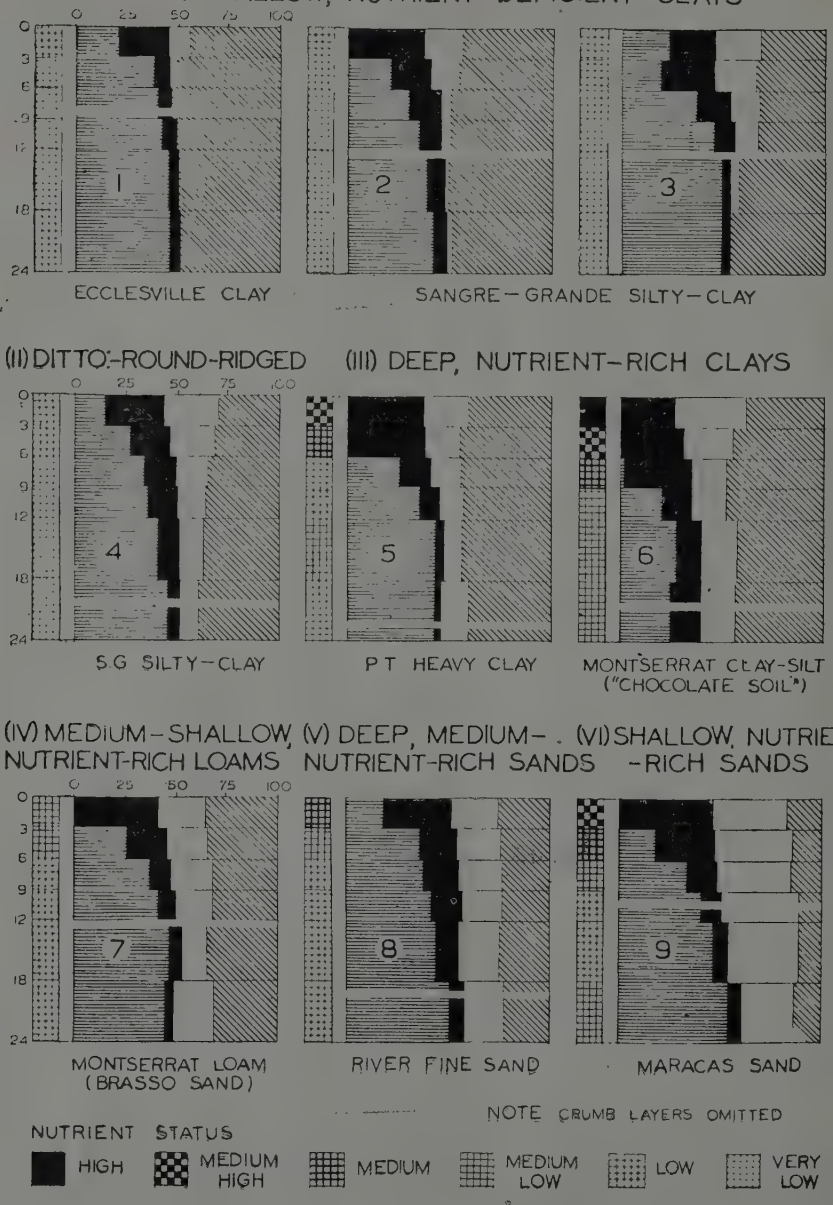
(7) The organic profile thus appears to be the main soil character associated with the satisfactory development, distribution and conformation of the root system of the cacao tree in Trinidad.

(8) *Shallow* cacao root systems, developed in nutrient-deficient compact acid clays or in sands having high water-tables, are generally characterised by a long thin tap-root, a sparse but widely-spread superficial lateral root-system and a well-marked fibrous surface root-mat (*biché* or *bichet*) associated with a thin crumb layer below the rotting leaf litter.

(9) *Deep* cacao root systems, developed in nutrient-rich well-structural calcareous clays, or in free-draining sands, are generally characterised by a short stout tap-root, an abundant much-divided deeply-set lateral root system and a diffuse fibrous root mass that exhibits small tendency to form a surface mat, though a thick crumb layer may cover the soil.

STRUCTURAL POROSITY OF CACAO SOILS

CLASSIFICATION ACCORDING TO ROOT RELATIONS



(10) The possibility of the fibrous root mass that develops when aeration and moistness are adequate functioning as a producer of a growth-promoting hormone in the cacao tree is further considered.

(11) The essential details demonstrating the relationships that exist between certain physical and chemical features of the soil and the distribution of cacao roots at the nine sites examined are epitomised in a diagram.

Explanation of the Diagram

(A) *Description*

(1) This diagram epitomises the essential data adduced in this article to demonstrate the close relationships that exist between certain physical and chemical features of the soil profile and the root-system of cacao trees growing at nine contrasted sites in Trinidad, representing seven important soil-types. Crumb layers and fibrous root-mats are not represented in the diagram.

(2) The headings (I) to (VI) describe the sites with regard to physiological depth and nutrient status.

(3) The lower limit of the main rooting zone is shown by a white *horizontal line* drawn across each profile diagram.

(4) The nutrient status is shown by the *narrow vertical column* set to the left of each profile diagram. The different cross-line patterns of the nutrient columns refer to six successive layers of the profile down to the 24-inches depth. Each pattern represents a particular nutrient status, as set out in the legend at the bottom of the page. Nutrient values were assessed by means of a scale of marks applied to the results of chemical analysis for nitrogen, phosphate, potash, etc., of representative soil samples (*See* text).

(5) Each profile diagram depicts the porosity features of the soil of the different profile layers down to the 24 inches depth. The *blackened areas* represent organic matter contents (per cent. × 10). The *horizontally-shaded* areas on the left represent the volume of solid soil (per cent.); the *obliquely-shaded* areas on the right represent capillary pore-space (per cent.); the *white unshaded* areas lying between them represent non-capillary pore-space (per cent.), *i.e.*, the degree of aeration of the freely-drained soil.

(B) *Deductions*

(1) The similarity between the extent of the unshaded areas representing non-capillary pore-space and the blackened areas representing organic matter content indicates a *close relationship between organic matter content and degree of aeration*, especially for the clay soils depicted by the profile diagrams comprising the first two horizontal rows.

(2) The association of blackened areas representing decreasing amounts of organic matter with column patterns representing diminishing nutrient status down the profile suggests a quantitative relationship between organic matter content and concentration of nutrients.

(3) The actual depth of the lower limit of the main rooting zone seems to be determined mostly by structural porosity, though it is greatest in the profiles having highest nutrient status.

EFFECT OF FERTILIZERS ON ORANGE YIELDS

In Bulletin No. 673 of the California Agricultural Experimental Station results of the six most recent fertilizer trials with orange trees conducted by the station over a period of many years are reported. The experiments with replications on plots of 7-16 trees were carried out at six different places under a variety of soil conditions. The reports are in the form of one progress report on a long-term experiment and five final summaries of other trials. The primary deficient elements were nitrogen and zinc, but organic matter was deficient also in some soils. In the Riverside experiments, covered by the progress report, the response to nitrogen applications was very marked. The most profitable doses per tree will partly depend on economic considerations since yield does not increase in proportion to the amount of fertilizer applied. The response to an application of 3 lb. per tree per year was good, but the result per unit was better with smaller applications. 1 lb. of nitrogen per year was found insufficient in the long run to maintain the supply in the soil. The following inorganic and organic fertilizers were found equally effective:—nitrates of soda and lime, sulphate of ammonia, urea, dried blood, cotton seed meal and such bulky organic manures as alfalfa hay, cereal and bean straw. The application of organic matter supplied by cover crops or as manure proved beneficial as well. In the absence of organic matter the response to zinc treatment was particularly pronounced. This element was most satisfactorily applied by means of foliage sprays. Experimenting with the supply of organic matter, it was found important to keep the carbon-nitrogen ratio well balanced. At a low rate of nitrogen the spring application of manure as the sole fertilizer and the growing of winter crops on manured soils in the absence of other fertilizers had a depressing effect on tree yield. Bulky organic materials should, therefore, always be supplemented with concentrated nitrogen treatment. On soil containing sufficient phosphate, potash, gypsum, limestone and sulphur, no benefit could be observed from supplying these materials. On results of the five other experiments agree well with these findings, which proves them to be valid for a wide range of conditions. With the exception of Sudan grass cover crops were shown to be beneficial and to supply all the organic matter required.—(*Horticultural Abstracts*, XIV, No. 1, 1944).

WITCHES' BROOM DISEASE INVESTIGATIONS

X. Loss of Pods in I.C.S. Clones at River Estate during 1943

BY

R. E. D. Baker and W. T. Dale

(*Department of Mycology and Bacteriology, Imperial College of Tropical Agriculture*)

The clones of I.C. Selections under trial in field 7 have been examined for pod resistance to witches' broom disease for the first time. Prior to 1943 the yields had been insufficient for detailed analysis, but in 1943, 17364 pods, of which 1757, or 10%, were attacked by witches' broom disease have been harvested from Sets I, II and III. (These figures are taken from the detailed yield records of these trees kept by the Botany Department of the Imperial College).

Set. 1 **Table I.**

Pods harvested during 1943

Clone I.C.S.	Total pods	Healthy pods	W.B.D. pods	O.D. pods	% W.B.D.
1 ...	2003	1738	202	63	10
3 ...	237	149	79	9	33
4 ...	204	187	13	4	6
5 ...	98	79	17	2	17
6 ...	1013	943	64	6	6
8 ...	1469	1119	287	63	19
	5024	4215	662	147	13

It is interesting to note that in this field, where strenuous attempts were made to control the disease, the percentage loss of pods was only about 10% while in the adjoining field 19, where no attempt was made at control, over the same period the percentage loss was 44%. The yields in pods from Set 1 are shown in Table I.

Table II shows the number of pods set during the dry months when infection by witches' broom disease was unlikely, and harvested during the months of July and August (no cacao was picked in May or June).

It is obvious therefore that these clones, with the exception of I.C.S.3, showed a considerable degree of disease avoidance, setting the bulk of their crop at a time when severe infection by witches' broom disease was not possible. (It is by no means certain that this will continue as the trees grow older).

Table III shows an analysis of pods set during the rest of the year when the chances of infection by the disease were greater.

Although sufficient figures are not yet available for detailed statistical analysis, it is at least interesting to notice that these 6 clones fall into

Table II

Pods harvested in July and August 1943

Clone I.C.S.	Total pods	% of Total yield	Healthy pods	Witches' broom disease pods	Other disease pods	% Witches' broom disease
1 ...	1105	55	1085	8	12	1
3 ...	43	18	41	0	2	0
4 ...	166	81	162	3	1	2
5 ...	62	63	58	3	1	5
6 ...	753	74	751	2	0	0
8 ...	854	58	787	39	28	5
	2983	59%	2884	55	44	2%

Table III

Pods harvested during the rest of the year

Clone I.C.S.	Total pods	% of Total yield	Healthy pods	Witches' broom disease pods	Other disease pods	% Witches' broom disease
1 ...	898	45	653	194	51	22
3 ...	194	82	108	79	7	41
4 ...	38	19	25	10	3	26
5 ...	36	37	21	14	1	39
6 ...	260	26	192	62	6	24
8 ...	615	42	332	248	35	40
	2041	41%	1331	607	103	30%

two groups, I.C.S. 1, 4 and 6 appearing possibly to show more resistance to the disease than I.C.S.3, 5 and 8. This difference, if it is a significant one, could be due to 'true' resistance, since 'disease avoidance' has already been eliminated. It is also encouraging that two of the most promising clones, I.C.S.1 and 6 are in the group, which is possibly the more resistant.

Comparable results for Set 2 are shown in Tables IV, V and VI and for Set 3 in Tables VII, VIII and IX.

Again, in all the clones with the exception of I.C.S.7, which appears to be a very poor clone, there is considerable disease avoidance. Taking all three sets together the following clones can be classed as showing some promise of disease resistance in addition to disease avoidance:—

I.C.S.1, 4, 6, 45, 98

as doubtful:—

I.C.S.2, 7, 9, 12, 53, 60

as poor:—

I.C.S.3, 5, 8, 16, 22

Three of the clones, I.C.S.1, 6, and 45, which are also promising for reasons such as high yield, high pod value, quality, etc., fall in the first group.

These results are however somewhat at variance with those obtained from 'seedling' trees and published in Nos. VIII and IX of this series, where no evidence for pod-resistance could be found. Until fully substantiated they must therefore be viewed with caution.

Set. 2 **Table IV**

Pods harvested during 1943

Clone I.C.S.	Total pods	Healthy pods	W.B.D. pods	O.D. pods	% W.B.D.
1 ...	1846	1728	106	12	6
7 ...	210	161	43	6	20
16 ...	1336	1119	204	13	15
22 ...	1136	974	153	9	13
45 ...	1601	1504	64	33	4
53 ...	1186	1049	128	9	11
	7315	6535	698	82	10

Table V

Pods harvested June, July and August

Clone I.C.S.	Total pods	% of Total yield	Healthy pods	Witches' broom disease pods	Other disease pods	% Witches' broom disease
1 ...	1507	82	1487	13	7	1
7 ...	83	40	75	7	1	8
16 ...	982	74	950	27	5	3
22 ...	799	70	769	24	6	3
45 ...	1351	84	1300	39	12	3
53 ...	799	67	775	22	2	3
	5521	75%	5356	132	33	2.5%

Table VI

Pods harvested during rest of the year

Clone I.C.S.	Total pods	% of Total yield	Healthy pods	Witches' broom disease pods	Other disease pods	% Witches' broom disease
1 ...	339	18	241	93	5	27
7 ...	127	60	86	36	5	28
16 ...	354	26	169	177	8	50
22 ...	337	30	205	129	3	38
45 ...	250	16	204	25	21	10
53 ...	387	33	274	106	7	27
	1794	25%	1179	566	49	32%

Set 3. **Table VII**

Pods harvested during 1943

Clone I.C.S.	Total pods	Healthy pods	W.B.D. pods	O.D. pods	% W.B.D.
1 ...	1225	1135	70	20	6
2 ...	488	441	41	6	8
9 ...	396	354	42	0	11
12 ...	622	561	45	16	7
60 ...	1089	925	127	37	12
98 ...	1205	1126	72	7	6
	5025	4542	397	86	8

Table VIII

Pods harvested in June, July and August

Clone I.C.S.	Total pods	% of Total yield	Healthy pods	Witches' broom disease pods	Other diseaes pods	% Witches' broom diseases
1 ...	879	72	844	23	12	3
2 ...	382	78	369	11	2	3
9 ...	275	69	273	2	0	1
12 ...	499	80	482	14	3	3
60 ...	701	64	664	19	18	3
98 ...	930	77	914	13	3	1
	3666	73%	3546	82	38	2%

Table IX

Pods harvested during the rest of year

Clone I.C.S.	Total pods	% of Total yield	Healthy pods	Witches' broom disease pods	Other disease pods	% Witches' broom disease
1 ...	346	28	291	47	8	14
2 ...	106	22	72	30	4	28
9 ...	121	31	81	40	0	33
12 ...	123	20	79	31	13	25
60 ...	388	36	261	108	19	28
98 ...	275	23	212	59	4	21
	1359	27	996	315	48	23%

WITCHES' BROOM DISEASE INVESTIGATIONS

XI. Observations on the Effect of Planting Interval on Witches' Broom Disease at River Estate

BY

R. E. D. BAKER AND W. T. DALE

(Department of Mycology and Bacteriology, Imperial College of Tropical Agriculture)

Preliminary observations at River Estate led to the suggestion being made that the close-planted cacao in field 18 was less severely attacked by witches' broom disease than that planted at greater intervals, and in March 1943 experiments were laid out to test this theory.

Field 18 consists of acre blocks planted 6 × 6, 8 × 8, 10 × 10 (without shade) and 12 × 12, 14 × 14, 16 × 16 and 18 × 18 feet (with immortel shade). As a preliminary it was decided to sample pods from the 6 × 6 and the 12 × 12 blocks. In order to obtain some replication, four plots were laid out in each block to give approximately equal yields; this was thought to give a better comparison than either plots of equal area or plots of equal numbers of trees.

After six months it was found that the 6 × 6 plots had produced 61% more pods per acre than the 12 × 12 plots with only 14% witches' broom diseased pods, compared with 22% in the 12 × 12 plots. It was accordingly decided that the experiment should be run for a further period of 6 months and be extended to include the 8 × 8 and the 18 × 18 blocks. Results are therefore available for all four blocks from 12/10/43 to 28/3/44 and for the 6 × 6 and 12 × 12 blocks from 17/3/43 to 12/10/43 as well.

These results, on the whole do not support the theory that close-planted cacao has fewer pods attacked by witches' broom disease; the 12 × 12 block is inexplicably worse than any of the other blocks sampled; but the results suggest that the close-planted trees are standing up better to the disease and are now yielding far more cacao per acre than the wider spacings. When the yield, of these blocks were last recorded about 1940 before witches' broom disease became serious, their yields were approximately the same, with the exception of the 10 × 10 block which always yielded poorly; now the yield of the 6 × 6 and the 8 × 8 blocks is approximately double that of the 12 × 12 and very considerably more than that of the 18 × 18 block.

The results from 12/10/43 to 28/3/44 are shown in Tables I and II.

Table I

Percentage Witches' broom pods by plots

Spacing	Plot 1	Plot 2	Plot 3	Plot 4	Block percentages
6x6 ...	56	50	49	41	49
8x6 ...	47	47	51	43	47
12x12 ...	69	55	58	57	62
18x18 ...	46	52	43	49	48

Percentage for field 50%

Table II

Effect of spacing on percentage of diseased pods

Spacing	% healthy pods	% W.B. pods	% other diseased pods
6 x 6 ...	25	49	26
8 x 8 ...	28	47	25
12 x 12 ...	14	62	24
18 x 18 ...	22	48	30
Percentage for field	23	50	27

The over-all percentage of pods destroyed by witches' broom disease of 50% is comparable with the 44% found in the neighbouring field 19 (See No. VIII of this Series) and emphasises the severity of the disease in this area. Only the 12 × 12 block differs appreciably from the over-all percentage.

The results for the 6 × 6 and 12 × 12 blocks for the 12 months from 17/3/43 to 29/2/44 are shown in Tables III and IV.

Table III

Percentage of Witches' broom pods by plots

Spacing	Plot 1	Plot 2	Plot 3	Plot 4	Block percentages
6 x 6 ...	46	41	42	35	41
12 x 12 ...	58	47	45	50	50

Over-all percentage 45%

Table IV

Spacing	% healthy pods	% W.B. pods	% other diseased pods
6 x 6 ...	32	41	27
12 x 12 ...	24	50	26
Over-all percentage ...	29	45	26

These tables show that the additional 6 months from 17/3/43 to 12/10/43, during which much less cacao was produced, made little difference to the final result. It must be concluded therefore that the planting interval in this field has little or no effect on the percentage of pods attacked by witches' broom disease.

A comparison of the yields of these blocks is given in Table V.

Table V

Spacing	Potential yield per acre (pods)		Yield per acre (calculated as lbs. dry cacao)	
	6 months	12 months	6 months	12 months
6 x 6 ...	9883	12295	824	1024
8 x 8 ...	8289		691	
12 x 12 ...	4483	6064	374	505
18 x 18 ...	6124		510	

These figures are high because in estimating the potential yield of the trees all diseased pods have been counted, and it was assumed that any pod which reached a length of 7.5 cms. would have ripened if it had not been destroyed by diseases or pests. The fact remains, however, that the closer spacings not only appear to be in better condition but are producing far more cacao than the wider spacings.

PROBLEMS OF THE KENYA COFFEE INDUSTRY

An article by S. Gillet in the *Mon. Bull. Coffee Bd. Kenya*, VIII, 87-8 deals with a number of defects in estate management, which are thought to be responsible for the deterioration of conditions in the Kenya coffee industry. The author's main point is that the coffee tree as a forest tree thrives only on soils rich in organic matter and that the application of artificial fertilizers is wasted where this condition does not prevail. The maintenance of a high organic content has also a direct bearing on soil conservation. Farmers are urged to consider the keeping of stock and the growing of bulk crops, it being unlikely that cheap cattle or goat manure from neighbouring African lands will be available after the war. The importance of delayed pruning and of allowing the trees to recover from die-back before any pruning is carried out is re-emphasized. Severe carbohydrate exhaustion produced by heavy pruning and bi-annual bearing is indicated as the cause of large areas becoming uneconomical. In this connection the significance of spraying for the control of leaf fall is also stressed. Many estates should decide on a planting programme at an early date.

CHEMICAL NOTES

(Compiled by the College Department of Chemistry and Soil Science)

Relation of Ascorbic Acid Concentration in Juice of Florida Grapefruit to Variety, Rootstock and Position of Fruit on the Tree

P. S. Harding and E. E. Thomas summarize as follows in a paper published in the *Journal of Agricultural Research* (Vol. 64, No. 1) the results of experiments on the ascorbic acid content of the juice of Florida grapefruit carried out in a commercial grove on the east coast of Florida: "The ascorbic acid concentration was determined for 390 individual grapefruits picked from outside and inside branches of 5 trees each of Marsh grapefruit grown on rough lemon rootstock, of Marsh grapefruit grown on sour orange rootstock, and of Foster (pink grapefruit grown on sour orange rootstock). The results showed that Florida grapefruit from various sources has high antiscorbutic properties. In this experiment the average ascorbic acid concentration was 0.40 milligram per milliliter of grapefruit juice. A relatively small but consistent difference was found in the ascorbic acid concentration in fruits obtained from outside and inside branches from the three sources; the outside fruit had the higher ascorbic acid concentration. This difference was found to be significant at the 1 per cent. level. The ascorbic acid concentration in fruits from the Marsh variety grown on rough lemon and on sour orange rootstocks was determined. A statistical study of these data showed a higher ascorbic acid content per milliliter of juice of fruit grown on rough lemon rootstock, but the difference was not significant. The ascorbic acid content of juice of fruits on the Marsh and Foster (pink) varieties of grapefruit, both of which were grown on sour orange rootstock, was also determined. The analysis of variance of these data indicates a higher ascorbic acid concentration in the Foster fruit. This difference was found to be highly significant (P=0.01)."

* * *

Performance of German Soils during last 100 Years and their State of Fertility under the Influence of Modern Fertilization

L. Schmitt. *Forschungsdienst* 12, 1-36 (1941); *Chem. Zentr.* 1941, II, 2246.—The maintenance of the nutrient supply at the normal level made possible through the introduction of commercial fertilizers has resulted, in conjunction with plant breeding, plant protection and improved methods of cultivation, in a mighty increase in German harvests. The increased production of straw and fodder resulting from the use of commercial fertilizers has resulted in an extraordinary increase in the production of stable manure so that the fertility of German soils under the influence of modern fertilizer application has not declined but has improved. Long-term experiments without stable manure have shown that the use of commercial fertilizers does not, in itself, injure the humus content of the soil but rather tends to increase that content through the increased production of root residues. The appearance of acid soils is not due to the use of commercial fertilizers but rather to the action of climatic forces. Thus it is known that forest soils tend strongly to become acid. In spite of the sharp increase in the use of commercial fertilizers the continued withdrawing of nutrients is not compensated, so that a further doubling of the use of commercial fertilizers is in the interest of maintaining the productivity of the soils. Soil investigations will afford the ground work for the proper use of these increased amounts of commercial fertilizers.—(*Chem. Abstracts*, 1944, Vol. 38, No. 10, p. 2429).

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Cane Trash for Cardboard and Wrapping Paper Manufacture.

K. V. Lonkar and S. N. Gundu Rao, in *Indian Sugar*, Vol. 7 (1944) No. 2, pp. 96.—While much has been written and something has been done about making cardboard and wrapping paper from bagasse, the utilization of cane trash for similar purposes has not been tried up to now. Experiments at Ravalgaon, to produce cardboard and wrapping papers from cane trash were started in December, 1941. Initial experiments having proved encouraging, a small commercial plant consisting of pressure digesters, koller-gangs, beaters, screw presses, and calendars has been installed and good quality cardboard and wrapping papers have been prepared. The practice consists in treating well cut trash in pressure digesters with sodium hydroxide or a mixture of carbonate and lime at a pressure of 25 to 30 lbs. per square inch for ten hours. Higher pressure reduces the time of digestion to about six hours. The digested material is then washed free of alkali, and the material is passed through an edgerunner. The pulp is then ready for making into cardboard. The material, however, is again subjected to the action of the beater, if wrapping and other varieties of paper are to be manufactured. The prepared material is given suitable sizing, loading and colouring. The further process is similar to that adopted in hand-made papers. The lifting is done in hand frames. After a number of cardboards have been collected into a couch, it is pressed in a screw press and the cardboard is further dried and pressed in calendars. It is then cut to proper size in shears and packed for marketing. With the introduction of automatic pulp lifting and drying equipments, it is expected that cane trash will provide one of the best raw materials for making good quality cardboard and packing papers. The quality of the cardboards is much superior in strength compared to those made out of rice, wheat and other straws, bagasse, etc. The amount of pure cellulose in cane trash is about 40 per cent, depending on the variety and age of the crop. Taking this yield into consideration, a 600-ton cane factory will provide sufficient raw material for a cardboard plant with a production capacity of 10 tons of cardboard per day throughout the year.—(*Sugar*, Vol. 39, No. 8, 1944).